Before the

FEDERAL COMMUNICATIONS COMMISSION

WASHINGTON, DC 20554

In The Matter of	)	
	)	
Section 68.4(a) of the Commission's Rules	)	RM-8658
Hearing Aid-Compatible Telephones		

Motion for Leave to file Supplemental Comments

1. QUALCOMM Incorporated ("QUALCOMM") hereby files this Motion, pursuant to Section 1.405(c) of the Commission's Rules, 47 C.F.R. § 1.405(c), for leave to file Supplemental Comments in the above captioned proceeding. QUALCOMM seeks authority to file these comments to correct and clarify some of the claims made in certain reply comments filed in this proceeding and to provide the Commission with a previously proprietary QUALCOMM report.

2. Section 1.405 (c) provides that no additional comments beyond reply comments may be filed unless authorized by the Commission. QUALCOMM believes that it would be appropriate for the Commission to authorize QUALCOMM to file its Supplemental Comments.

3. A number of parties in this proceeding filed reply comments in which they discussed QUALCOMM test reports. One of the reports discussed was not part of the record in this proceeding. QUALCOMM is including a copy of that report as a part of its Supplemental Comments. In addition, QUALCOMM's Supplemental Comments clarify and correct claims made in certain reply comments

regarding the report that QUALCOMM submitted with its comments in this proceeding. QUALCOMM believes it is important that the Commission have QUALCOMM's interpretation of QUALCOMM's reports available in the record in this proceeding.

4. For the foregoing reasons, QUALCOMM requests that the Commission grant this motion for leave to file Supplemental Comments in this proceeding.

Respectfully submitted,
QUALCOMM Incorporated

Kevin J. Kelley
Vice President External Affairs

1233 20th Street, N.W.
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August 18, 1995

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FEDERAL COMMUNICATIONS COMMISSION
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Section 68.4(a) of the Commission's Rules	)	RM-8658
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Supplemental Comments Of QUALCOMM Incorporated

1. QUALCOMM Incorporated ("QUALCOMM") hereby submits Supplemental Comments in the above captioned proceeding. QUALCOMM had no intention of filing comments in this proceeding. However, when a FCC staff member contacted QUALCOMM and asked about a QUALCOMM report that CTIA officials had discussed with the Commission, QUALCOMM felt that it was appropriate for it to share its own analysis of its own test results with the Commission. Several parties addressed the QUALCOMM test results in their reply comments. QUALCOMM is filing these supplemental comments to correct and clarify some of the claims made by these parties. QUALCOMM did not take a position on the public policy issues raised by the HEAR-IT-NOW Petition in its original filing in this proceeding and it does not do so herein.

CTIA's Reply Comments

2. QUALCOMM's earlier report that CTIA discussed with the Commission staff and others is clearly marked on the cover and every page as being a proprietary document. Before this filing, QUALCOMM had only released the test report to a single scientific worker in Europe. However, QUALCOMM recently has learned that its

proprietary report has been widely circulated. For this reason, QUALCOMM is including the proprietary report as Attachment A to this filing.

3. In its Reply Comments, CTIA states that it, "understands that Qualcomm has conducted comparative tests at 200 mw for GSM technology operating at 800 MHz in addition to the results it included in Attachment A of Qualcomm's response."[1] CTIA cites a trade press report as its authority for what is contained in the QUALCOMM proprietary report.[2] However, CTIA does quote material from the proprietary report, without citing a source, in its Technical Appendix.[3]

4. CTIA suggests that the Commission should only consider QUALCOMM's test results if "the Commission has the benefit of Qualcomm's full analysis of the tests."[4] The Commission has QUALCOMM's full analysis of the tests. QUALCOMM submitted it in the report it filed with its comments.

5. In its Reply Comments, CTIA states that, "By qualifying its statement with modifiers such as 'with no objectionable interference,' and in most parts of a well designed system,' QUALCOMM has fudged its conclusions and stopped short of claiming that CDMA technology causes no interference with hearing aids currently available."[5] This statement might lead some readers to believe that QUALCOMM was trying to mislead the Commission. It was not.

6. CTIA appears to be taking the position that there is no difference between interference and objectionable interference. There is a vast difference between a level of interference that is

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[1] CTIA Reply Comments, 6.
[2] *Id.*, n. 15.
[3] *Id.*, Technical Appendix, n. 11(The information included in this note can be found in the second table on page 5 of QUALCOMM's November 9,1993 Report).
[4] CTIA Reply Comments, 6.

just barely detectable by a non hearing impaired person, which many hearing impaired person very likely could not even detect, and a level of interference that will prevent a hearing impaired person from using a wireless telephone.

7. CTIA states that, "the QUALCOMM report does not use the appropriate U.S. GSM standard for comparison."[6] There is only one U.S. standard that is based on the European GSM standard. It is for use in the PCS bands. When QUALCOMM conducted PCS tests, it used the U.S. standard. When QUALCOMM did tests in cellular bands, it used the appropriate standard for these bands.

8. In its Technical Appendix, CTIA recites a list of the classes of mobile stations provided for in the CDMA standards and concludes that, "Regardless of the U.S. CDMA standard selected, there is no CDMA mobile unit designed to operate at the 200 milliwatt maximum output power utilized by Qualcomm for its test."[7] CTIA's conclusion may lead some to believe that a mobile unit that does not have a maximum power equivalent to maximum allowed by the standard does not meet the standard. This is incorrect. Any CDMA cellular mobile that has a maximum power (when commanded to by the system to deliver maximum power) between 200 milliWatts and 1 Watt complies with the IS-95 standard for a Class III mobile. Similarly, any CDMA PCS portable that has maximum transmitter power (when commanded to by the system to deliver maximum power) between 200 milliWatts and 1 Watt complies with ANSI J-STD-008 standard for a Class II personal station.

9. The mobile units that QUALCOMM used in its tests were designed to operate at maximum transmitter power just exceeding 200 milliWatts--at the lower end of the range permitted by the standards. QUALCOMM is not aware of any manufacturer that is

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[5] *Id.*, (emphasis added).
[6] *Id.*, 7.
[7] *Id.*, Technical Appendix, 2.

providing mobile units that operate at the maximum transmitter power levels specified in the standard. QUALCOMM is providing equipment with a transmitter power level that meets the needs of all known CDMA system designs.

10. QUALCOMM believes that it is important to understand two fundamental differences between CDMA systems and GSM systems. First, in the full rate constrained mode (as well as in the normal mode during full voice activity) the CDMA mobile unit transmits continuously. As a result, its peak power and average power are the same. GSM systems, on the other hand, transmit only one eighth of the time. This means that a CDMA system operating at the same average power as a GSM system will have a peak power that is one eighth of the peak of the GSM system. That is, CDMA systems have an inherent 9 dB peak power advantage over GSM systems with equal average power.

11. Furthermore, as discussed below, at equal distances from the base station, GSM systems operate at a significantly higher average power, and hence even more than 9 dB greater peak power, than the CDMA system. At maximum range for each mobile, which is greater for the CDMA mobile, each has peak power equal to its maximum power - 200 milliWatts for CDMA and 1 Watt for a corresponding GSM unit.

12. Second, there is fundamental difference between the role of power control in a CDMA system and in GSM system. When engineers first suggested the use of CDMA technology for wireless services, many said the system would not work because of the near-far problem. Because multiple users occupy the same channel at the same time, a CDMA system can only achieve its maximum capacity if the power received at the base station from each user is approximately the same. That is the signal received from a "far" user must be approximately the same as the signal received from a "near" user.

13. In a mobile communications system, the near-far problem can only be solved by constantly dynamically controlling the power of each user so that its transmitted power is the minimum required to achieve the desired communications link quality. Thus, precise power control is an inherent part of the CDMA system. An added benefit of using this very precise power control is that CDMA systems can achieve equivalent link performance at energy per bit to noise density ratios (E_b/N_o)[8] that are substantially lower than those of GSM systems. These two factors, coupled with the superior error correcting code performance of CDMA, the diversity provided by the CDMA RAKE receiver, and the use of soft handoff are what allow CDMA systems to transmit at peak power levels that are 10 to 17 dB lower than mobile units in other system operating in equivalent conditions at less than maximum range. QUALCOMM and others have conducted numerous tests that confirm the power levels of CDMA mobile units.[9]

14. In its Technical Appendix, CTIA claims that a chart that shows the various standard power levels established for PCS 1900 mobiles, demonstrates that, "power levels below 20 milliwatts also predominate."[10] Again, CTIA should appreciate the difference between specifications that exist in a standards document and real world data. Power control in a GSM system is a service option that is available to the system operator. QUALCOMM understands that most GSM service providers did not use the power control service option when they initiated cellular service. QUALCOMM does not know what percentage of GSM operators actually use the power control option. QUALCOMM notes that when Cox tested the

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[8] It would be more accurate to use the notation E_b/Io for CDMA system since the noise will result mainly from interference from other users rather than from thermal noise. See, Viterbi, Andrew .J., CDMA Principles of Spread Spectrum Communications, 9, n. 2 (Addison-Wesley Publishing Company, 1995).

[9] See e.g., QUALCOMM Incorporated Quarterly Progress Report for Personal Communications Services, Experimental License Call Sign: KK2XBJ, (File Number: 2345-EX-PL91), (JULY 19, 1993); Cox Enterprises, Inc. Experimental License Progress Report, KF2XFR (File No. 1641-EX-R-92) San Diego, CA. (February 22, 1994).

[10] CTIA Reply Comments, Technical Appendix, 5.

1900 MHz GSM system in San Diego, it reported to the Commission that the mobile units had a transmitter power of 30.0 dBm (1.0 Watt).[11] There was no indication that the power control option was used or even if it was available. When the operator does not exercise the power control option, the mobile units operate at their maximum power level. CDMA mobiles rarely operate at their maximum power levels.

15. QUALCOMM does not understand CTIA's comments concerning the full rate constrained mode of vocoder operation. CTIA states that, "Qualcomm, however, fails to point out that devices such as vocoders which are designed to achieve 'full rate constrained' mode of operation are not the standard for CDMA systems."[12] The CTIA statement might lead some to believe that QUALCOMM used a non standard vocoder in its tests. It did not. The standard CDMA vocoder can run at any of four rates 8, 4, 2, or 1 kilobit per second. The lower rates are used during periods of low speech activity. In the full rate constrained mode the system simply instructs the vocoder to remain in the highest rate mode. The feature will only be available to those users that need it to avoid the possibility of hearing aid interference. As QUALCOMM noted in its comments, this feature will only be turned on when the transmitter power exceeds a preset level, such as 50 milliWatts.[13] QUALCOMM's tests indicate that below this power level, there will be no objectionable interference to hearing aid users.

16. QUALCOMM began investigating methods to ensure that its technology was usable with hearing aids as soon as it learned of the GSM problems. QUALCOMM hopes that CTIA will join others in applauding and supporting QUALCOMM's efforts to ensure that this superior technology is available to all hearing aid users.

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[11] Cox Enterprises, Inc. Experimental License Progress Report, KF2XFR (File No. 1641-EX-PL-90) San Diego, CA, 6, (May 20, 1994).
[12] CTIA Reply Comments, 7.
[13] Comments of QUALCOMM Incorporated, n. 10.

The GSM MoU's Reply Comments

17. In its reply comments, the GSM MoU made claims concerning the accuracy of QUALCOMM's comments about the Danish test results.[14] What QUALCOMM said was that QUALCOMM's tests showed that, "it is very unlikely that any hearing aid user could make a telephone call using a GSM portable with a hearing aid assisted ear. This result is consistent with the findings contained in other tests reports from Australia, New Zealand and Denmark that QUALCOMM has reviewed as part of its research in this area."[15]

18. QUALCOMM reviewed two reports from Denmark as part of its research in this area. One was the report the MoU identified in its Reply Comments and the other was report presented by Professor Ole Lauridsen in London last year. The first report concluded that 84% of the Danish hearing aids tested could not be used in the hearing assisted ear. The report also included results for Norwegian hearing aids that showed that about 85% of those could not be used in the hearing aid assisted ear.[16] Professor Lauridsen's report indicated that he tested 14 hearing aids and that 13 of them could not be used within 0.5 meters of the subject hearing aid.[17] That is, at least 92% of the hearing aids he tested were incompatible with GSM handsets.[18] Thus, QUALCOMM's test results are consistent with the results of the Danish tests.

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[14] Reply Comments of GSM MOU Association, Attachment 1,2.

[15] Comments of QUALCOMM Incorporated, Attachment A,1.

[16] *Interference with Hearing Aids Caused by GSM Digital Cellular Telephones and DECT Digital Cordless Telephones*, National Telecom Agency Denmark, 20(28 June 1984)(Hereinafter, "Telecom Denmark").

[17] Lauridsen, Ole M., *EMC and the New Modulation Technologies*, 9, presented at "Cellular: The Next Generation," London May 10-11, 1994.

[18] In a 26 March 1995 letter to Chairman Reed Hundt, Professor Lauridsen claims that the existence of a European Union EMC directive, "means that hearing aid users can successfully and comfortably use a 2 watt, handhold GSM telephone in conjunction with a hearing aided ear without interference." QUALCOMM does not understand how Mr. Lauridsen can make such a statement when all the available data, including his own, indicate that very few hearing aid users will ever be able to use a 2 watt GSM phone with the hearing aid assisted ear.

19. QUALCOMM believes that the GSM MoU claim that the report "determined that 62% of the modern in-the-ear hearing aids used in Denmark could be worn while using a 2 watt GSM phone,"[19] is incorrect. What the report said was that 62% of the in-the-ear hearing aid tested were in GSM immunity category I.[20] The report describes hearing aids in this category as follows:" In many cases it will be possible to use these hearing together with a 900 MHz, 2 W handportable GSM telephone in the same ear as the hearing aid."[21] Since the report does not contain any results obtained with actual hearing aid use with real portables, it is difficult to predict what percentage of such hearing aids could be used with a GSM phone.

20. The Australian report submitted with the comments of the GSM MoU and CTIA indicates that only one unaltered hearing aid out of a representative sample of the hearing aids used in Australia was rated as "sometimes usable" when used with a 2 watt GSM portable.[22] It was described as, "near the limit of usability."[23] All other untreated hearing aids were rated as "unusable".

21. In addition, the Danish report clearly states that ITE (in-the-ear) hearing aids, "are primarily used to remedy slight to moderate hearing handicaps"[24] and thus, "existing equipment of this type cannot be used to compensate for all kinds of hearing handicap."[25] Perhaps more important, only about 25% of the hearing aids tested were the ITE type. That is, only 62% of 25% of the hearing aids tested were in a class in which it may be possible to use a 2 watt phone using the hearing aid assisted ear.

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[19] Reply Comments of GSM MOU Association, 4.
[20] Telecom Denmark, 20.
[21] Id., 15 (emphasis added).
[22] National Acoustic Laboratories Report No 131, *Interference to hearing Aids by the Digital Mobile Telephone System, Global System for Mobile Communications, GSM*, 32 (May 1995) (Hereinafter "NAL Report No. 131").
[23] *Id.*, n.§.
[24] Telecom Denmark, 18.

22. The GSM MoU claims the "QUALCOMM study incorrectly concludes that a hearing user will be disturbed by other people's use of a GSM portables several meters away."[26] What QUALCOMM said was that its tests results showed that "a GSM portable when located within a distance of 1 to 3.5 meters from a hearing aid would cause audible interference."[27] This is correct and is consistent with the results in other reports that QUALCOMM has reviewed.

23. In citing the Danish report to support its questioning of QUALCOMM's results, the MoU once again seems to have a different understanding of what the report says. The Danish test did not use detectability as measure of interference as QUALCOMM did in its tests. Instead they used a quantity described as an overall input-related interference level sound pressure level (OIRIL SPL) of 55 dB.[28] The report describes this as an interference level that "seems acceptable."[29] That is, an interference level much higher than that which would be classified as just detectable.

24. The GSM MoU claims that the QUALCOMM, "study incorrectly states in the introduction that a GSM handportable <u>always</u> will transmit a peak power 'at least 10 to 17 dB (or 10 to 50 times) greater than CDMA phones'."[30] What QUALCOMM said was, "All other conditions made equal, GSM telephones will transmit at a peak power at least 10 to 17 dB (or 10 to 50 times) greater than CDMA phones thus creating far more severe interference."[31] This is correct. As described above, the CDMA power control and other system features ensure that the CDMA mobiles will always be

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[25] *Id.*, 24.
[26] Reply Comments of GSM MOU Association, Attachment 1,2
[27] Comments of QUALCOMM Incorporated Attachment A, 7.
[28] Telecom Denmark, 14.
[29] *Id.*
[30] Reply Comments of GSM MOU Association, Attachment 1,2
[31] Comments of QUALCOMM Incorporated, attachment A, 1. .

transmitting at the minimum possible transmit power level. This is not true for GSM systems.

25. In another section of its reply comments, the MoU suggests that there is an inconsistency between QUALCOMM's 1900 MHz test results and the Danish results.[32] First, the GSM MoU incorrectly states that the QUALCOMM data presented in the first table on page 5 of attachment A was taken at 1900 MHz. It was not. Even if it were, the GSM MoU analysis would be flawed because, once again, QUALCOMM tested for detectability of the interference and the Danish tests used DECT category I. This is similar to the GSM category I described above. That is, "In many cases (hearing aids in this category) may be used with an 1800 Mhz 250 mW DECT telephone in the same ear as the hearing aid."[33] Second, and perhaps more important, the Danish 1900 Mhz tests were done using the DECT signal structure; not the GSM signal structure as indicated in the MoU reply comments.

26. Finally the MoU claims that, "it is incorrect to compare a 2 Watt GSM-induced interference with interference to a lower peak power CDMA transmission ... ."[34] QUALCOMM tested each phone at its maximum transmit power. QUALCOMM's position is that the most important variable in making such tests is the peak transmitter power of the phone. Thus, it is valid to test each phone at its maximum transmit power to get a "worst case" comparison.

BellSouth's Reply Comments

27. In its Reply Comments BellSouth states, "Unsurprisingly, the only industry support for the petition came from QUALCOMM, ..."[35] BellSouth is mistaken. QUALCOMM did not support the

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[32] Reply Comments of GSM MOU Association, Attachment 1,4
[33] Telecom Denmark, 14(emphasis added).
[34] Reply Comments of GSM MOU Association, Attachment 1,5.
[35] Reply Comments of BellSouth, 9-10.

petition. QUALCOMM takes no position on whether the Commission should grant or deny HEAR-IT-NOW's petition

28. BellSouth also states that, "QUALCOMM included 'test results' purporting to compare GSM and CDMA with respect to hearing-aid interference, but its results are fundamentally flawed."[36] To support its claim BellSouth states, "For example, QUALCOMM tested its own CDMA digital phone against a simulated GSM TDMA signal achieved by 'AM modulating an RF signal generator."[37] BellSouth does not explain why it believes that using an AM modulated signal generator is a fundamental flaw. However, if that is its position, it should have pointed out that this was the same method used in the Australian report submitted to the Commission by the GSM MoU and CTIA and cited by BellSouth in its reply comments. The Australian report describes its GSM test signal as "a 900 Mhz carrier ... 80% amplitude modulated by a 1000 Hz sine wave."[38] The Danish report discussed above describes its simulated GSM test signal as a 900 Mhz carrier 100% AM pulse modulated at 217 Hz with a 1:8 duty cycle.[39] Are these test results fundamentally flawed also?

29. Next BellSouth claims that QUALCOMM, "used higher power for the GSM phone than will be used in United States GSM-based PCS networks."[40] BellSouth is incorrect again. When QUALCOMM did the 1900 MHz GSM tests, it used the correct U.S. power levels.

Conclusions

30. QUALCOMM hopes that these supplemental comments have clarified any confusion that may have may have been caused by the reply comments discussed herein. QUALCOMM's reiterates that its only reason for participating in this proceeding is to ensure that

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[36] *Id.*, 10.
[37] *Id.*, N.27.
[38] NAL Report No 131, 10.
[39] Telecom Denmark, 13.
[40] Reply Comments of Bell South, N. 27.

its test results and its analysis of them are correctly presented to the Commission.

Respectfully submitted,

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Attachment A

TEST REPORT

Measurement of RF Interference by CDMA and GSM Digital Cellular Portable Transceivers on Hearing Aids

Eber F. Lambert
Thomas B. Frazier

November 9 1993

INTRODUCTION

The following report details a series of tests performed by QUALCOMM to assess the extent of audible interference in hearing aids caused by the transmission of CDMA signals. The CDMA portable transmission is gated on and off in a pseudo-random manner with the effective duty cycle (filling factor) being a function of the activity of the variable rate vocoder. Vocoder rate varies as a function of voice activity and system parameters, hence not only does the relative location of burst vary randomly in time but the number of bursts per unit time varies as well. The net effect of this after the composite CDMA signal is passed through an AM detector, is an audio output which is spectrally spread rather than a tone or set of harmonically related tones which one would observe for a periodically gated RF signal of fixed duty cycle such as the GSM TDMA signal.

For an appropriate comparison of interference caused by GSM vs CDMA transmissions it is necessary to operate the phones at relative signal levels which arise from comparable use. In practice, the transmit signal levels of both GSM and CDMA are constantly changing in response to characteristics of the radio channel. However, in normal field conditions, including a wide range of multipath environments, both indoor and outdoor, etc., CDMA phones transmit at power levels approximately 10 to 14 dB below the transmit power levels of GSM phones under the same conditions.

Therefore, to properly compare interference, one must compare the interference caused by the two types of phone with the GSM phone operating at a fixed power level 10 to 14 dB greater than that of the CDMA phone. This is the proper comparison because GSM phones and CDMA phones used in identical situations will exhibit this ratio of relative transmit power. In the tests conducted in this report, a 10dB power ratio between GSM and CDMA was used to be conservative. Test were performed comparing GSM at 2W peak power to CDMA at 200mW. Data was also taken for GSM operating at 200mW, for completeness, in order to evaluate differences specific to the waveforms alone.

The tests performed can be divided into two categories: subjective and objective. The subjective tests were performed by a group of listeners identifying the presence of audible interference while the objective tests were spectral measurements of the peak and average audio level at 10dB above the noise floor of the hearing aid under test. The 10dB above noise floor criteria was found to be the approximate "annoyance" level cited in the NAL/TRL report. The independent variable recorded for all these test was the distance between the hearing aid and the radiating antenna. In addition to the measurements made, recordings of the interference were made and miscellaneous additional tests were performed as discussed in the result sections.

TEST SET UP DESCRIPTION

All tests were performed in a non-anechoic, non-RF shielded room (7m x 4.5m x 2.5m). Hearing aids were place on a wooden extension 1 meter above the floor. The transducer output from the hearing aid was coupled into a 2mm (I.D) plastic tube 46 cm in length the other end of which was coupled to a BK2639 microphone via a 2cc acoustic coupler. The frequency response of the tube/coupler segment was found not to significantly effect the composite audio frequency response of the set up by comparing the noise floor through the tube with the noise floor the in-ear aids coupled directly to the microphone. The measured composite frequency response (~100Hz-3kHz) was set by the hearing aids under test. The microphone drove a BK5935 preamplifier which was connected to the FFT analyzer and audio mixer to drive headphones and DAT recorder.

The radiating element was a connectorized 6 in (15cm) "rubber duck" antenna commonly used on portable UHF transceivers attached to a cable and hand held (no additional ground plane). The antenna was driven by a 5W linear power amp (Motorola PAA-0810-24-SL) through a section of double shielded coax (RG-58) for both waveforms. Power was calibrated at the antenna connection point by measuring average power with modulation removed for GSM and average power in fixed full rate for CDMA (no gating).

The simulated GSM/TDMA signal was generated with a function generator (HP8116A) driving the AM modulation port of a Fluke 6062 RF signal generator. The pulse rate was 217 Hz, duty cycle was set to 1/8, RF frequency was 825MHz and AM modulation set at 99%. The CDMA waveform was taken from a CD7000 portable phone with special test code inserted to allow for setting fixed output power and any fixed vocoder rate including a variable rate (Markov). The phone was powered externally by a linear DC supply to removed any effects of battery charge level on the data. The RF output was taken from the car kit connector and attenuated via software/keypad entry to drive the PA and set power at the radiating element.

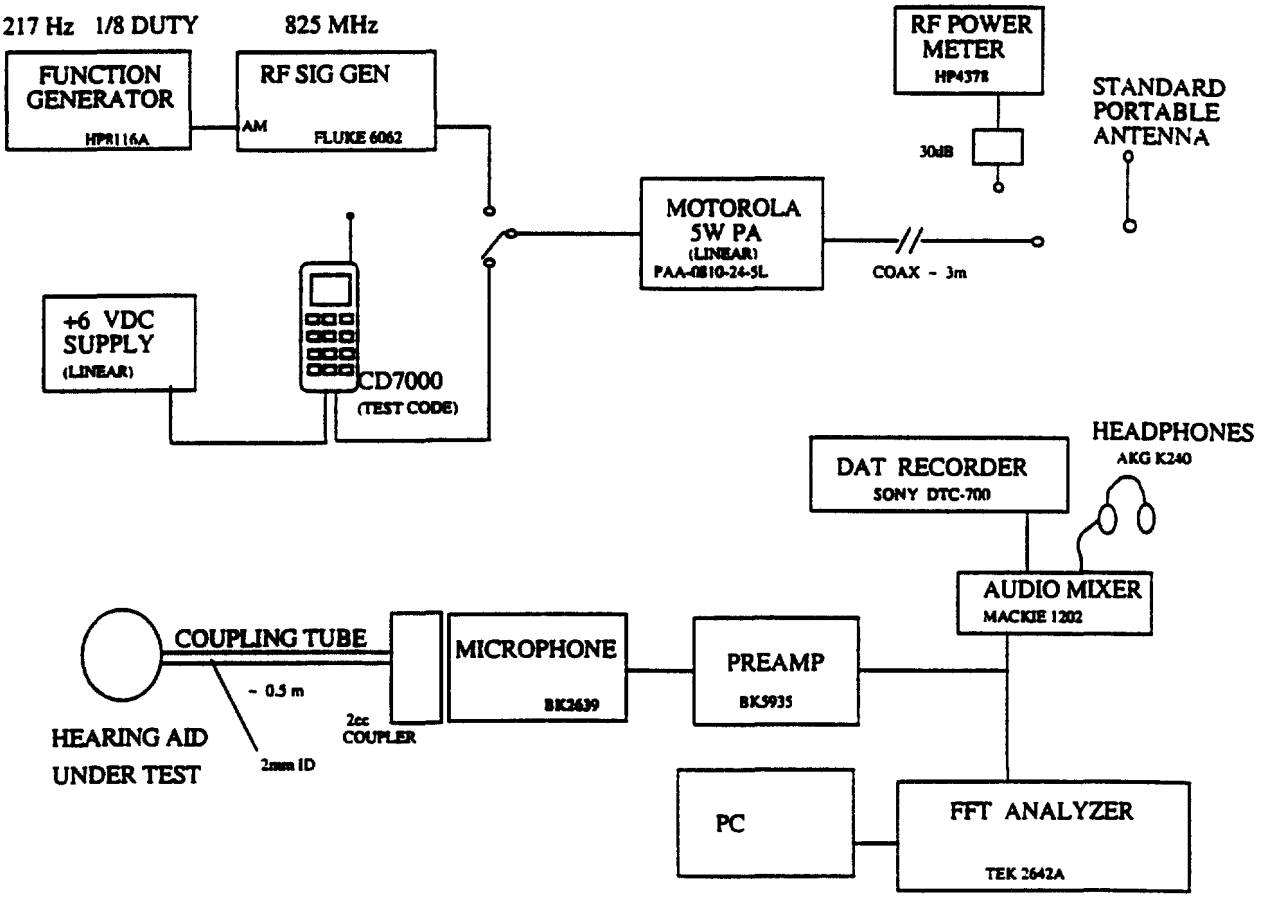


FIGURE 1
HEARING AID INTERFERENCE EVALUATION TEST SET UP

HEARING AIDS TESTED

Ref	Model	Type
BE1	Phonak PP-C-L-4	Behind Ear
BE2	Phonak PP-SC-L	Behind Ear
IE1	Rexton RX 93 J2151	In Ear
IE2	Omni ADV 35-93-380169	In Ear
IEC	Omni Imp 36-93-390082	In Ear canal

TEST PROCEDURE

LISTENING TESTS

Listening tests were performed on 4 individuals using the set up described above. The group was made up of two adult males (30 and 35 years old), a 69-year old female and 8-year old male. Additional data was taken on a hearing impaired adult male.

All tests were perform such that the hearing aid surface that would face away from the head was directed toward the source of interference. For low power/close proximity tests, several angles of approach were tried with the most sensitive (interference detected at furthest distance) being identified and used in subsequent tests. In essence each hearing aid presented somewhat of a unique antenna pattern based on its style. The distance accuracy for close-in measurements (<0.5m) based on measurement, repeatability of path of approach and orientation of hearing aid is estimated at +/- 5cm while measurement greater than 0.5 meters have an estimated accuracy of +/- 10%.

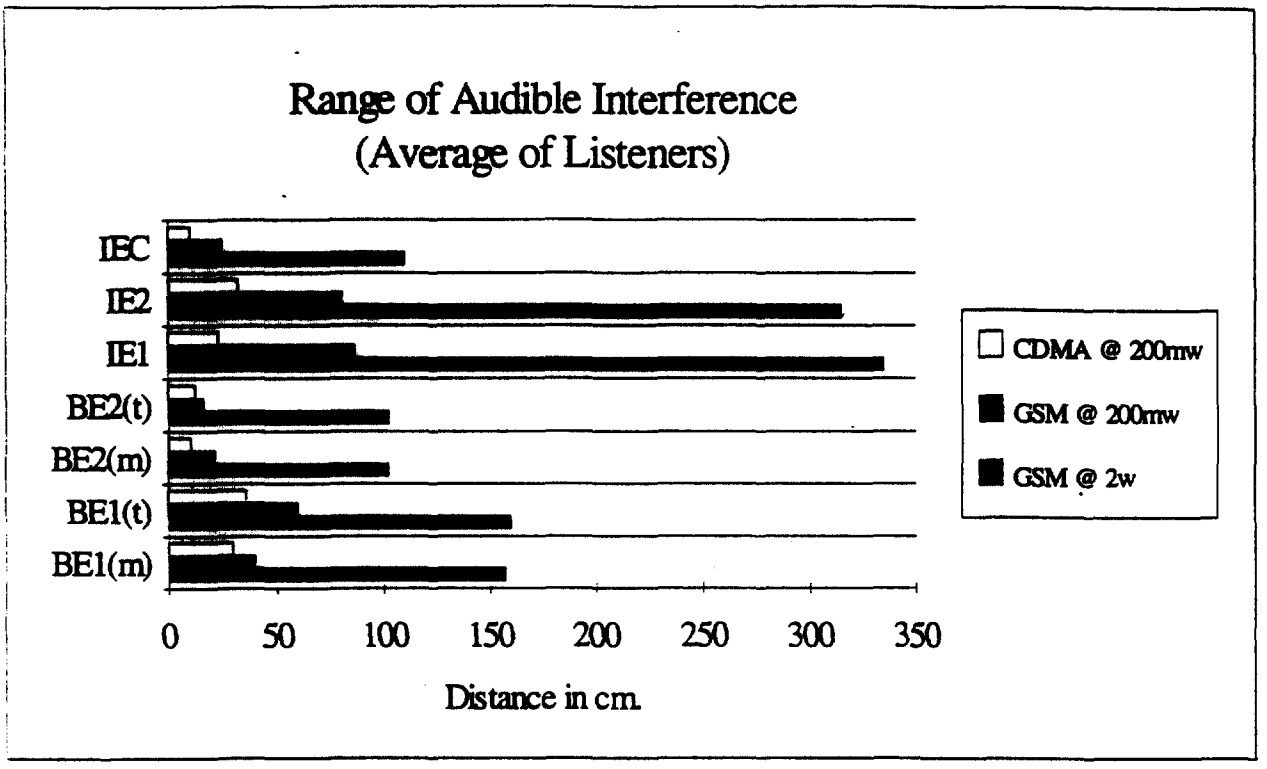
Hearing aids were set at maximum or near full volume. Headphone amplifier gain was adjusted for a comfortable listening volume for normal speech levels in the room. Additional preamp gain (30dB) was added for the in-ear style hearing aids such that comparable volume was achieved for a given sound check. This was approximated based on comparison with the behind ear aids, NOT calibrated to a SPL in the room. It was noted that a 10 dB reduction in this additional gain did not significant affect the detected distance.

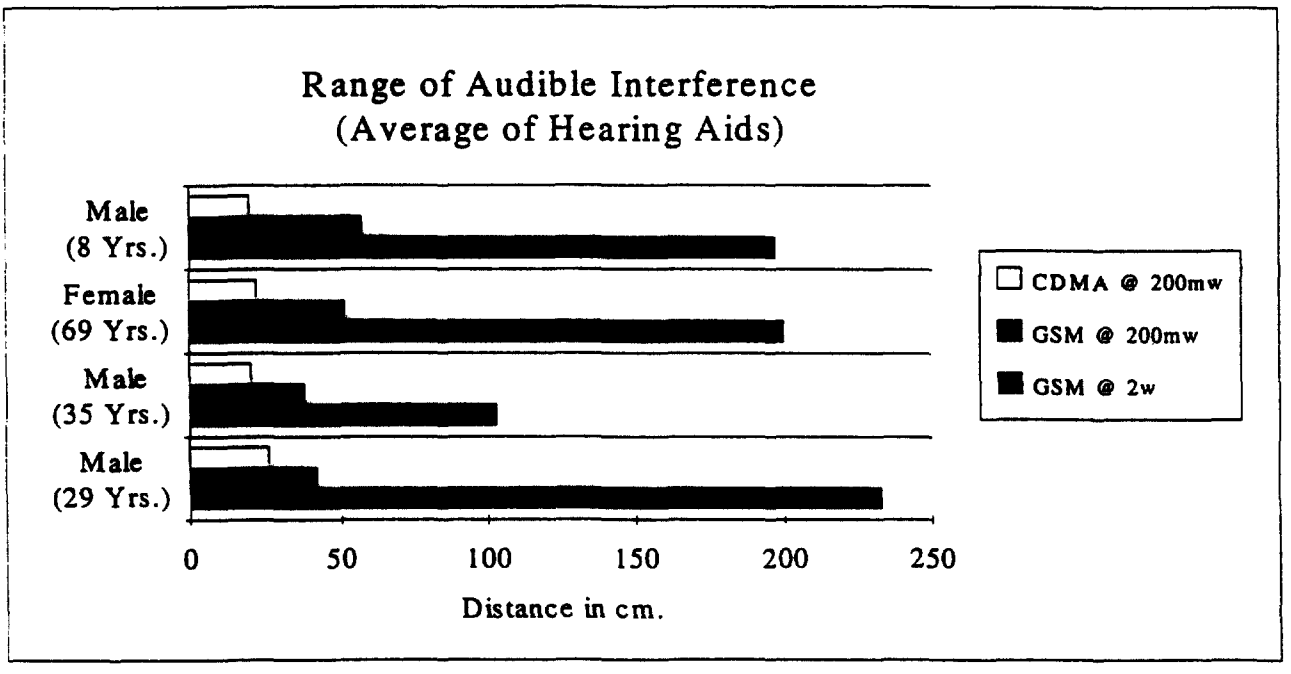
The radiating antenna was generally held normal to the floor, although in constant lateral motion (and somewhat rotated) to avoid effects of fading. During close proximity tests, the antenna was held normal to the path of approach. The antenna was moved from a distance where no interference was detected toward the hearing aid until the listener detected interference above the room ambient level (no speech during tests). The distance from the hearing aid to radiating antenna was recorded.

RESULTS:

Results indicate that interference from variable rate CDMA at maximum power (200mW) is audible when the transmitting antenna is within 0.5m (See Figure 2) for all tested hearing aids and listeners. Conversely, GSM at maximum handheld transmit level (2W peak) shows a range of 1 to 3.5 meters for audible interference. The GSM waveform at 200mW peak transmit power exhibits a range of detectability 50 to 100% larger than that of the CDMA waveform at equal power. Further tests were run on both waveforms operating at 20mW which indicates the range of detectability to be nearly equal considering the measurement accuracy and the test repeatability which were sensitive to antenna/hearing aid relative orientation as well as near field peaks and nulls. Range of detectability was 2 to 11cm for CDMA and 5 to 15 cm for GSM.

Figure 2


Range of Audible Interference
(Average of Listeners)
IEC
IE2
IE1
BE2(t)
BE2(m)
BE1(t)
BE1(m)
0
50
100
150
200
250
300
350
Distance in cm.
CDMA @ 200mw
GSM @ 200mw
GSM @ 2w


Range of Audible Interference
(Average of Hearing Aids)
Male
(8 Yrs.)
Female
(69 Yrs.)
Male
(35 Yrs.)
Male
(29 Yrs.)
0
50
100
150
200
250
Distance in cm.
CDMA @ 200mw
GSM @ 200mw
GSM @ 2w

Additional tests were also performed on the different fixed vocoder rates and the range of detection was found to be approximately equal with that of the variable rate. The exception was Full Rate which was only detectable within 4cm (worse case) the sound of which was that of pink noise ("sounds like the ocean") and not considered intolerable. Subsequently the interference heard in variable rate contains frequent "drop outs" when the vocoder goes to full rate which likely yields a higher threshold of discernability above background noise than the constant "buzz" of the detected GSM/TDMA signal.

For listener #4 a set of measurements were made to determine at what power level the CDMA signal became audible for each hearing aid with the radiating antenna 2cm from the hearing aid and adjusted vertically to give the maximum level of interference (found to be approximately the center of the radiating antenna). Results were as follows:

BE1 (m)	BE1 (t)	BE2 (m)	BE2 (t)	IE1	IE2	IEC
3.6 dBm (2.3mW)	-0.5 dBm (0.9mW)	8.0 dBm (6.3mW)	-1.6 dBm (0.7mW)	-3.3 dBm (0.5mW)	0.7 dBm (1.2mW)	1.5dBm (1.4mW)

To validate the results of the subjective testing, a hearing impaired adult male volunteer was tested in the same manner using his hardware (Phonak PE 845). The results were as followed:

Hearing Impaired Listener	CDMA @ 200mW	GSM @ 200mW	GSM @ 2W
Distance at which interference detected	25cm	30cm	100cm
Distance interference became "annoying"	8cm	14cm	65cm

The results indicate that the relative findings of the listening tests are valid. One might further conclude that a hearing aid placed in or on the ear would distort its effective "receive antenna pattern" or the incident field such that closer proximity to the radiating element is required to achieve the same level of audible interference. Furthermore, any future listening tests would best be performed with a large sample of hearing impaired individuals with a variety of hearing aids for more accurate and possibly less condemning results.

SPECTRAL ANALYSIS TESTS

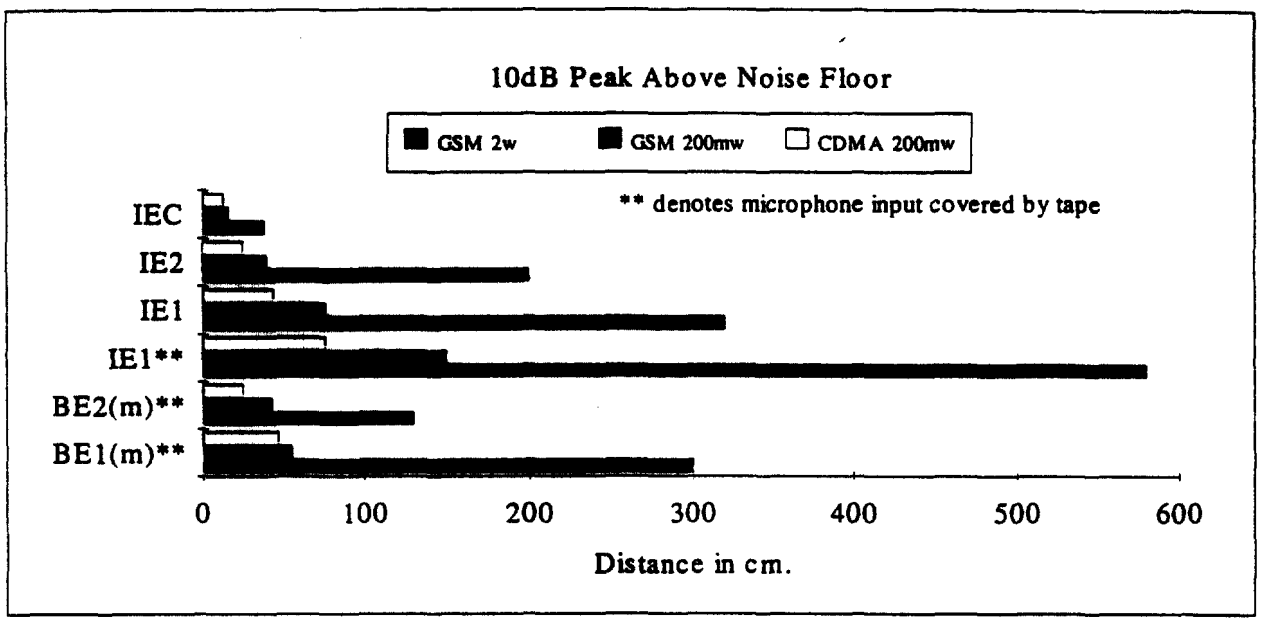
10dB Tests:

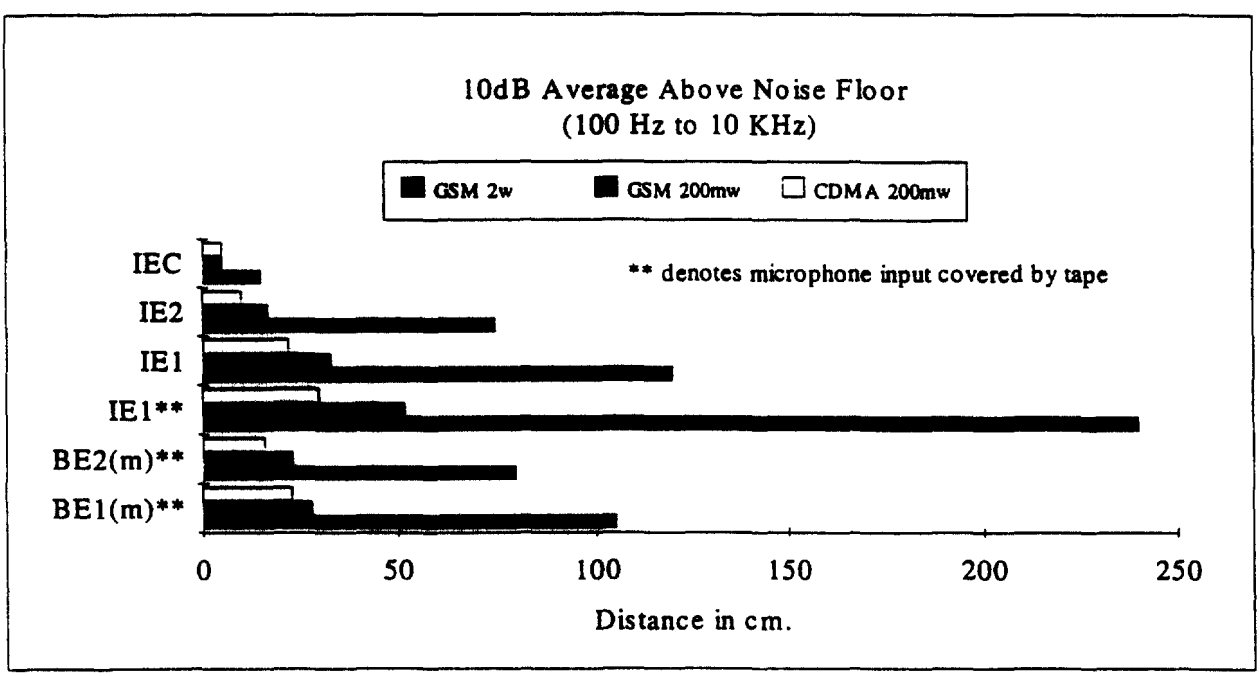
A set of measurements were tabulated for each hearing aid and hearing aid mode for the distance at which the audio power level and peak audio level was found equal to 10dB above the hearing aid/room noise floor. The hearing aids with AGC were measured with the microphone input obstructed. The PEAK measurement is the distance at which any spectral component within the 100Hz to 3kHz band exceeds 10dB above the noise floor. The AVERAGE measurement is the distance at which the integrated interference power in the 100Hz-10kHz band exceeds 10dB above the noise floor (see Figure 3). Data for the tele-coil (t) mode of the BE hearing aids was omitted due to the high average noise floor the hearing aid exhibits in this mode.

Figure 3

Distance at 10 dB Above the Hearing Aid Noise Floor

	BE1(m)** cm.		BE2(m)** cm.		IE1** cm.		IE1 cm.		IE2 cm.		IEC cm.	
	Avg.	Pk.	Avg.	Pk.	Avg.	Pk.	Avg.	Pk.	Avg.	Pk.	Avg.	Pk.
CDMA 200mw	23	47	16	25	30	76	22	44	10	25	5	13
GSM 200mw	28	55	23	43	52	150	33	76	17	40	5	16
GSM 2w	105	300	80	130	240	580	120	320	75	200	15	38





Spectral Plots:

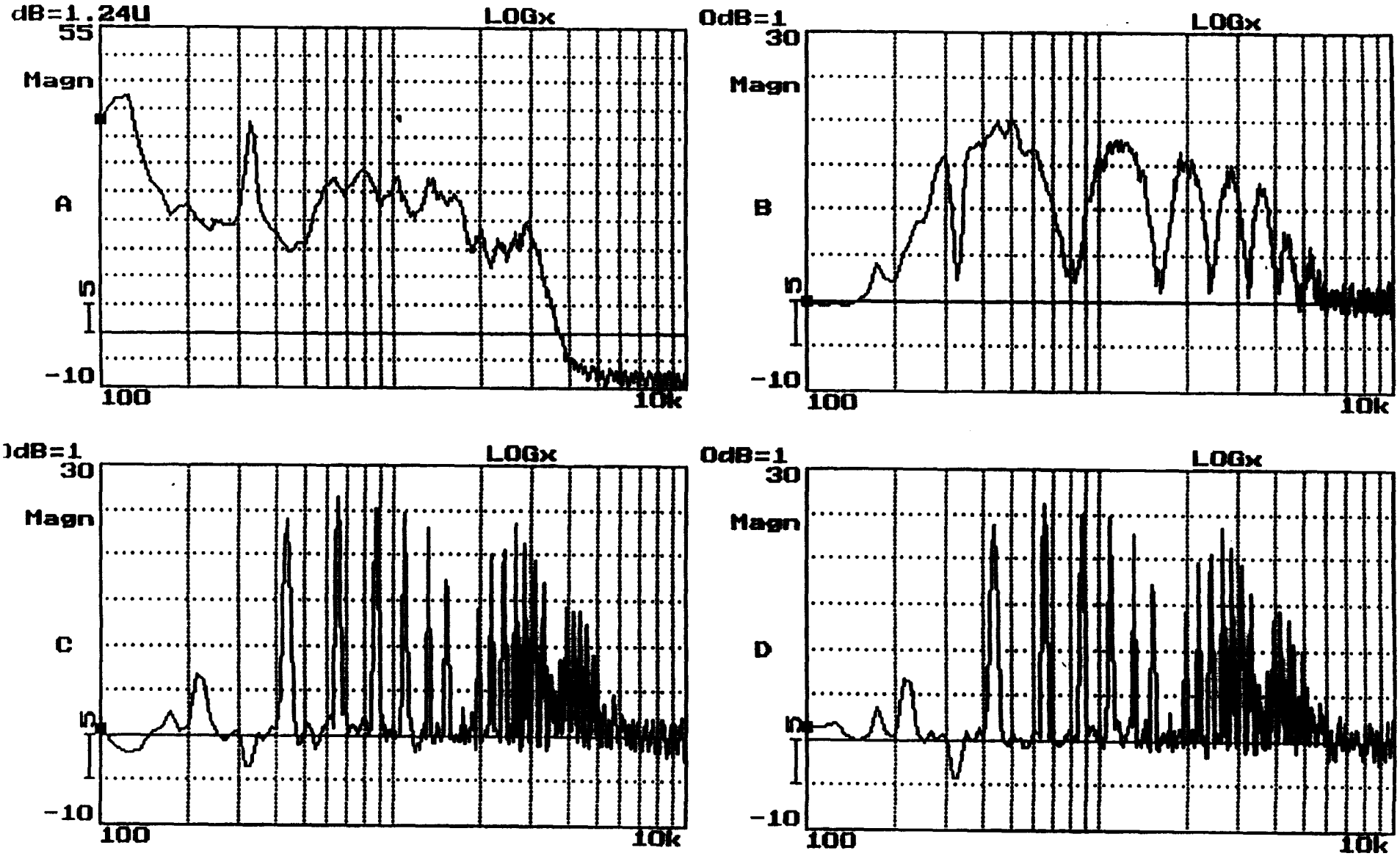
An example of the spectral measurements described above for the worse case hearing aid (IE1) appear in Figure 4. The tones evident in the noise floor plots were found to be due to fluorescent lighting (120Hz) and equipment fan noise permeating the equipment enclosure (~320Hz). The plots (B through D) were normalized to remove these.

A set of 4 plots were compiled for each hearing aid and hearing aid mode with the radiating element fixed at 0.5 meters from the hearing aid. Due to the similarity of performance in the different classes of hearing aid, the In-Ear type hearing aids were averaged into a single set of plots (Figure 5) and the Behind-Ear type hearing aids into the second set of plots (figure 6). The plots show: A) hearing aid noise floor; B) CDMA @200mw variable rate; C) GSM @ 200mW; D) GSM @ 2W. For each plot B through D, the analyzer math function was used to subtract the noise floor yielding a spectrum of dB above the ambient noise floor.

CONCLUSION:

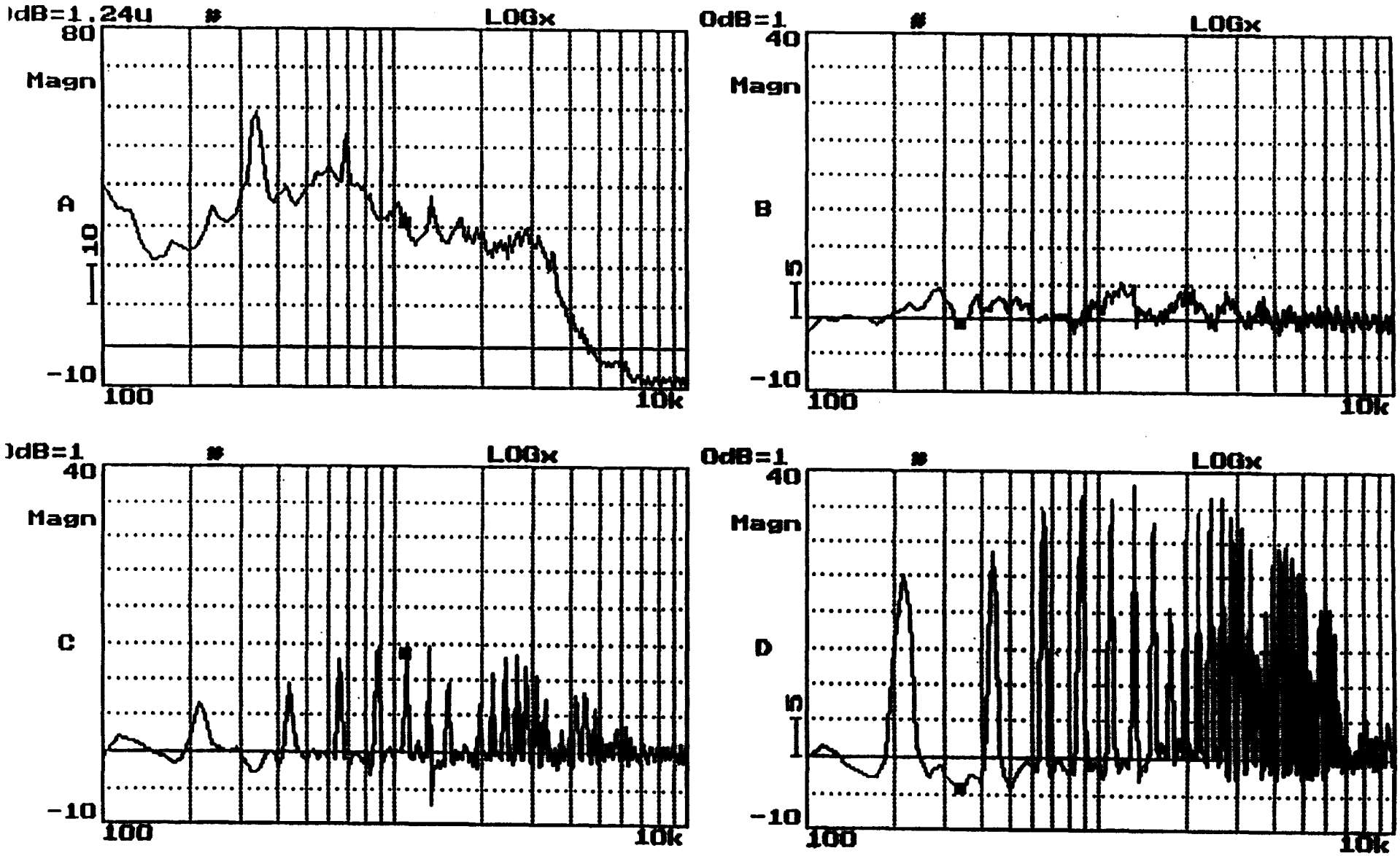
The tests performed indicate that CDMA transmissions from a portable transceiver can create audible interference when operating at maximum transmit power within 0.5 meters of various hearing aids. The range at which the interference occurs is primarily a function of transmit power, hence for a GSM transceiver transmitting at the specified 2-watt output level the range is significantly larger than that of a CDMA portable. Furthermore, in normal operation the CDMA portable operates at an average power significantly less than its maximum transmit power which would further reduce the range of audible interference in hearing aids.

A secondary effect observed is that, due to the periodic nature of the signal, the GSM TDMA signal is more readily discernible at a lower audio level than the pseudo-random CDMA signal. The net effect is that range of audible interference is noticeably less for CDMA than for GSM with both operating at the same RF power level.



A IE1 with the microphone taped Background Noise
B CDMA 200mw @ 10dB Distance = 30cm Normalized
C GSM 200mw @ 10dB Distance = 52cm Normalized
D GSM 2w @ 10dB Distance = 240cm Normalized

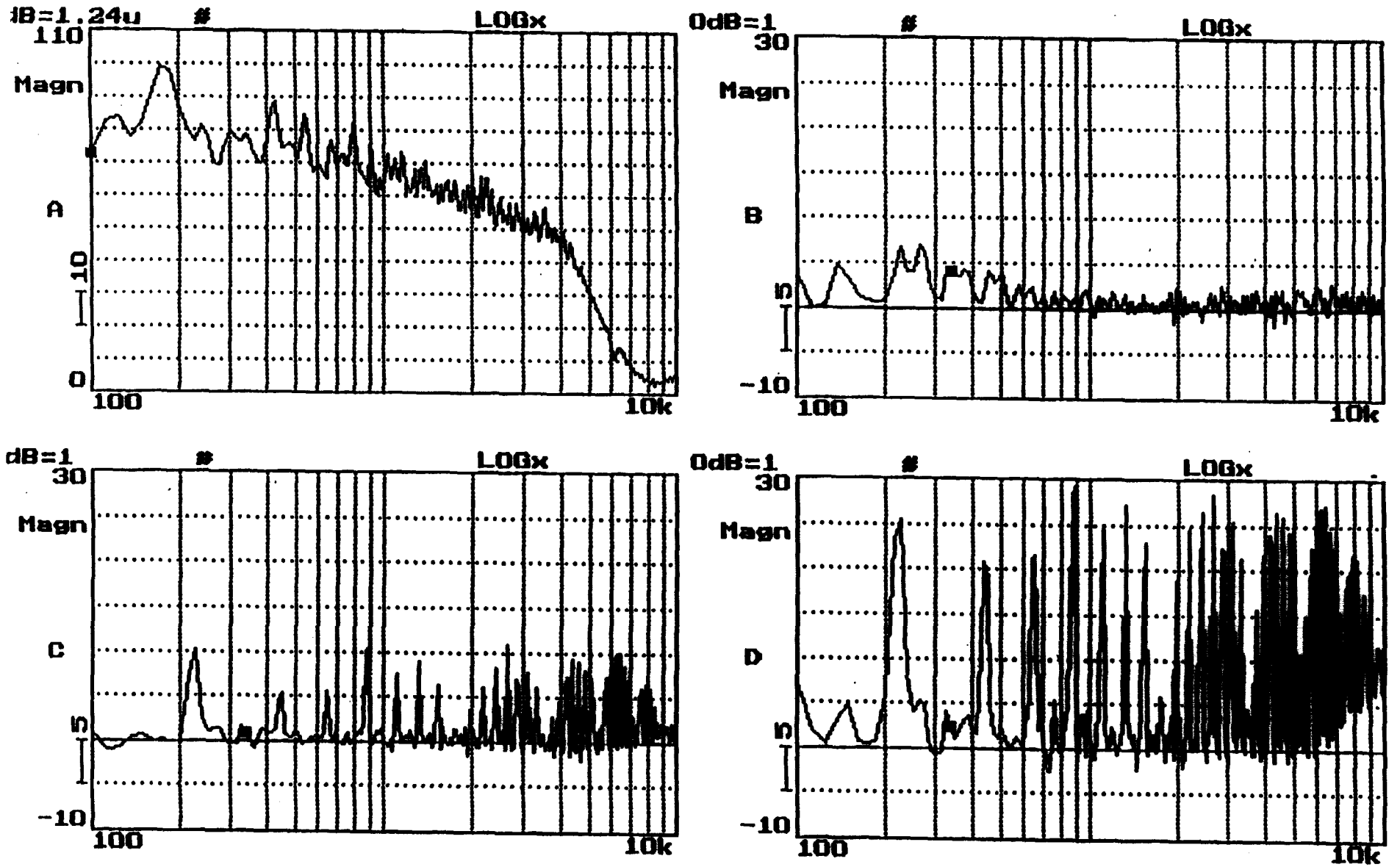
FIGURE 4



A Hearing Aid Noise Floor
B CDMA @ 200mw Normalized
C GSM @ 200mw Normalized
D GSM @ 2w Normalized

FIGURE 5

*** ALL Plots Averaged Over Three Hearing Aids IE1, IE2, and IEC. ***



A Hearing Aid Noise Floor
B CDMA @ 200mw Normalized
C GSM @ 200mw Normalized
D GSM @ 2w Normalized

*** ALL Plots Averaged Over Hearing Aids BE1(m),BE1(t),BE2(m), and BE2(t). ***

FIGURE 6